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FINAL REPORT
FOR
JANTX2N2369A

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Prepared
For

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FOREWORD

This report is a summary of the work performed on NASA Contract NAS8-31944. The investigation was conducted for the National Aeronautics and Space Administration, George C. Marshall Space Flight Center, Huntsville, Alabama. The Contracting Officer's Technical Representative was Mr. F. Villella.

The short-term objective of this preliminary study of transistors, diodes, and FETS is to evaluate the reliability of these discrete devices, from different manufacturers, when subjected to power and temperature step stress tests.

The long-term objective is to gain more knowledge of accelerated stress testing for use in future testing of discrete devices, as well as to determine which type of stress should be applied to a particular device or design.

This report is divided as follows: description of tests, figures, tables, and appendix.



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1.0 INTRODUCTION/SCOPE

DCA Reliability Laboratory, under contract NAS8-31944 for NASA/Marshall Space Flight Center, has compiled data for the purpose of evaluating the effect of power/temperature step stress when applied to a variety of semiconductor devices. This report covers the transistor JANTX2N2369A manufactured by Raytheon and National Semiconductor.

A total of 48 samples from each manufacturer was submitted to the process outlined in Table 1. In addition, two control sample units were maintained for verification of the electrical parametric testing.

2.0 TEST REQUIREMENTS

2.1 Electrical

All test samples were subjected to the electrical tests outlined in Table 2 after completing the prior power/temperature step stress point. These tests were performed using the Fairchild Model 600 high-speed computer-controlled tester. Additional bench testing was also required on the devices.

2.2 Stress Circuit

The test circuit, shown in Figure 1, was used to power all of the test devices during the power/temperature stress conditions. The current was set by I_C and the V_{CE} voltage was varied in order to comply with the specified power rating for this device. At least one of the devices was subjected to maximum rated power (MRP). All the remaining devices were subjected to no less than 90% of MRP. See Figure 1 for load resistance values and voltages.



2.3 Group I - Power Stress

Thirty-two units, 12 from Raytheon and 20 from National Semiconductor, were submitted to the Power Stress Process. The transistors were stressed in 500-hour steps at 50, 100, 125, 150 and 175 percent of maximum rated power for a total of 2500 hours or until 50% or more of the devices in a sample lot failed.* Electrical measurements were performed on all specified electrical parameters after each power step. See Table 1.

2.4 Group II - Temperature Stress I

Thirty-two units, 24 from Raytheon and 8 from National Semiconductor, were submitted to the Temperature Stress I Process. Group II was subjected to 1600 hours of stress at MRP in increments of 160 hours. The temperature was increased in steps of 25°C, commencing at 75°C and terminating at 300°C or until 50% or more of the devices in a sample lot failed.* Electrical measurements were performed on all specified electrical parameters after each temperature step. See Table 1.

2.5 Group III - Temperature Stress II

Thirty-two units, 12 from Raytheon and 20 from National Semiconductor, were submitted to the Temperature Stress II Process. Group III was subjected to 112 hours of stress at MRP in increments of 16 hours. The temperature was increased in steps of 25°C, commencing at 150°C and terminating at 300°C or until 50% or more of the devices in a sample lot failed.* Electrical measurements were

*Conditions for failure:

- A) Open or short
- B) Leakage exceeds the MIL limit by 100 times
- C) Other parameters exceed MIL limits by 50% or more.



performed on all specified electrical parameters after each temperature step. See Table 1.

3.0 DISCUSSION OF TEST RESULTS

3.1 Group I - Power Stress

3.1.1 Raytheon. The Raytheon sample lot completed the entire 2500-hour Group I testing with one catastrophic failure. The failure occurred 10 hours into the 175% MRP step. Serial number 2168 failed the maximum $V_{CE(SAT)1}$, $V_{CE(SAT)2}$, and minimum h_{FE} limits. Typical characteristics of this sample lot's performance were:

- 1) The mean value for I_{CES} changed 32.61 nA from an initial mean of 35.80 nA to a final mean of 3.19nA.
- 2) The mean value for $V_{CE(SAT)1}$ changed 2.0mV from an initial mean of 145.7mV to a final mean of 143.7mV.
- 3) The mean value for $V_{CE(SAT)2}$ changed .30mV from an initial mean of 294.1mV to a final mean of 294.4mV.
- 4) The mean value for h_{FE} changed 3.99 from an initial mean of 80.21 to a final mean of 84.20.

The control units for this sample lot remained constant throughout the entire Group I testing.

3.1.2 National Semiconductor. The National Semiconductor sample lot completed the entire 2500-hour Group I testing with four catastrophic failures. The first failure occurred 250 hours into the 100% MRP step. Serial number 2096 failed the maximum I_{CES} , $V_{CE(SAT)1}$, and minimum h_{FE} limits. The next failure occurred 10 hours into the 125% MRP step. Serial number 2102 failed the maximum I_{CES} limit. Serial number 2099 was also removed from the testing at this point but was a MIL- Σ -19500 limit failure, not catastrophic. The last two failures occurred 10 hours into the 175% MRP



step. Serial numbers 2098 and 2104 failed the maximum $V_{CE(SAT)1}$, $V_{CE(SAT)2}$, and minimum h_{FE} limits. Typical characteristics of this sample lot's performance were:

- 1) The mean value for I_{CES} changed 42.17nA from an initial mean of 45.27nA to a final mean of 3.10nA.
- 2) The mean value for $V_{CE(SAT)1}$ changed 4.20mV from an initial mean of 155.1mV to a final mean of 159.3mV.
- 3) The mean value for $V_{CE(SAT)2}$ changed 31.2mV from an initial mean of 327.9mV to a final mean of 359.1mV.
- 4) The mean value for h_{FE} changed .01 from an initial mean of 64.77 to a final mean of 64.78.

The control units for this sample lot remained constant throughout the entire Group I testing.

3.1.3 Statistical Summary - Group I

Table 4 outlines the results of Group I - Power Stress Process for each of the four electrical parameters and all measurement points for both Raytheon and National Semiconductor.

3.2 Group II - Temperature Stress 1

3.2.1 Raytheon. The Raytheon sample lot completed a total of 1440 hours before the lot was stopped because 11 catastrophic failures occurred. The first two failures occurred 160 hours into the 225°C-temperature step. Serial number 2188 failed the minimum h_{FE} limit. Serial number 2190 failed the maximum $V_{CE(SAT)2}$, and minimum h_{FE} limits. The last nine failures occurred 160 hours into the 275°C-temperature step. Serial numbers 2149 and 2150 failed the maximum $V_{CE(SAT)2}$ limit. Serial numbers 2152, 2182, 2183, 2185, 2186, and 2189 failed the minimum h_{FE} limit. Serial number 2187 failed the maximum $V_{CE(SAT)1}$, $V_{CE(SAT)2}$, and minimum h_{FE} limits. Typical characteristics of this sample



lot's performance were:

- 1) The mean value for I_{CES} changed .961nA from an initial mean of 3.304nA to a final mean of 2.388nA.
- 2) The mean value for $V_{CE(SAT)1}$ changed 581.6mV from an initial mean of 144.4mV to a final mean of 726.0mV.
- 3) The mean value for $V_{CE(SAT)2}$ changed 729.7mV from an initial mean of 293.3mV to a final mean of 1.023V.
- 4) The mean value for h_{FE} changed 52.27 from an initial mean of 80.86 to a final mean of 28.59.

The control units for this sample lot remained constant throughout the entire Group II testing.

3.2.2 National Semiconductor. The National Semiconductor sample lot completed 1440 hours before the lot was stopped because eight catastrophic failures occurred. The first failure occurred 160 hours into the 125°C-temperature step. Serial number 2136 failed the maximum $V_{CE(SAT)2}$ limit. The next three failures occurred 160 hours into the 200°C-temperature step. Serial numbers 2134 and 2135 failed the minimum h_{FE} limit. Serial number 2138 failed the maximum $V_{CE(SAT)2}$ limit. The last four failures occurred 160 hours into the 225°C-temperature step. Serial numbers 2133 and 2140 failed the maximum $V_{CE(SAT)2}$ limit and minimum h_{FE} limits. Serial number 2139 failed maximum $V_{CE(SAT)2}$ limit. Serial number 2137 failed the maximum limits for $V_{CE(SAT)1}$ and $V_{CE(SAT)2}$. Typical characteristics of this sample lot's performance were:

- 1) The mean value for I_{CES} changed 409.99μA from an initial mean of 10.82nA to a final mean of 410.0μA.
- 2) The mean value for $V_{CE(SAT)1}$ changed 3.342V from an initial mean of 153.5mV to a final mean of 3.495V.
- 3) The mean value for $V_{CE(SAT)2}$ changed 4.020V from an



initial mean of 323.9mV to a final mean of 4.344V.

- 4) The mean value for h_{FE} changed 54.27 from an initial mean of 67.00 to a final mean of 12.73.

The control units for this sample lot remained constant throughout the entire Group II testing.

3.2.3 Statistical Summary - Group II

Table 5 outlines the results of Group II - Temperature Stress I testing for each of the four electrical parameters and all of the measurement points pertaining to both Raytheon and National Semiconductor.

3.3 Group III - Temperature Stress II

- 3.3.1 Raytheon. The Raytheon sample lot completed the entire 112-hour Group III testing with three catastrophic failures. The first failure occurred 16 hours into the 150°C-temperature step. Serial number 2171 failed the minimum h_{FE} limit. The next failure occurred 16 hours into the 175°C-temperature step. Serial number 2178 failed the maximum I_{CES} limit. The last failure occurred 16 hours into the 200°C-temperature step. Serial number 2172 failed the maximum I_{CES} limit. Typical characteristics of this sample lot's performance were:

- 1) The mean value for I_{CES} changed 1.22nA from an initial mean of 1.699nA to a final mean of 2.919nA.
- 2) The mean value for $V_{CE(SAT)1}$ changed 12.5mV from an initial mean of 135.4mV to a final mean of 147.9mV.
- 3) The mean value for $V_{CE(SAT)2}$ changed 54.9mV from an initial mean of 271.3mV to a final mean of 326.2mV.
- 4) The mean value for h_{FE} changed 15.15 from an initial mean of 74.39 to a final mean of 59.24.

The control units for this sample lot remained constant throughout the entire Group III testing.



3.3.2 National Semiconductor. The National Semiconductor lot completed the entire Group III testing with a total of nine catastrophic failures. The first failure occurred 16 hours into the 150°C-temperature step. Serial number 2129 failed the minimum h_{FE} limit. The next four failures occurred 16 hours into the 175°C-temperature step. Serial numbers 2117, 2119, 2120, and 2122 failed the maximum I_{CES} limit. The next failure occurred 16 hours into the 200°C-temperature step. Serial number 2116 failed the maximum I_{CES} limit. The last three failures occurred 16 hours into the 275°C-temperature step. Serial numbers 2118 and 2121 failed the maximum $V_{CE(SAT)2}$ limit. Serial number 2114 failed the maximum $V_{CE(SAT)1}$, $V_{CE(SAT)2}$ and minimum h_{FE} limits. Typical characteristics of this sample lot's performance were:

- 1) The mean value for I_{CES} changed 499.495 μ A from an initial mean of 499.5 μ A to a final mean of 4.581nA.
- 2) The mean value for $V_{CE(SAT)1}$ changed 437.7mV from an initial mean of 644.5mV to a final mean of 206.8mV.
- 3) The mean value for $V_{CE(SAT)2}$ changed 42.7mV from an initial mean of 806.8mV to a final mean of 764.1mV.
- 4) The mean value for h_{FE} changed 5.82 from an initial mean of 62.72 to a final mean of 56.90.

The control units for this sample lot remained constant throughout the entire Group III testing.

3.3.3 Statistical Summary - Group III

Table 6 outlines the results of Group III - Temperature Stress II testing for each of the four electrical parameters and all of the measurement points pertaining to both Raytheon and National Semiconductor.



4.0 FINAL DATA SUMMARY

Table 7 statistically summarizes the change in the mean value from the zero-hour data to the final data. The graphs of Figures 2 and 4 plot the cumulative percent failures versus the temperature stress level for Group II - Temperature Stress I, and Group III - Temperature Stress II. The graphs of Figures 3 and 5 plot the time step for Group II (160 hours) and Group III (16 hours) versus the temperatures T_1 and T_2 calculated from Figures 2 and 4. Tables 8 and 9 summarize the failures encountered for all three stress groups. The failures are separated into two categories: catastrophic failures in Table 8 and parametric failures in Table 9. The data from Table 8 was used as a source for the graphs in Figures 2 and 4. Figures 2 and 4 were used as a source for the graphs in 3 and 5 respectively. Junction temperature is plotted on an inverse hyperbolic scale.

5.0 CONCLUSIONS

Both the National Semiconductor and the Raytheon parts suffered a loss of gain while generally continuing to maintain good junction quality with low leakage. This situation indicates loss of emitter efficiency as the cause of the decline in gain. The loss of emitter efficiency is in turn due to migration of gold and possibly other impurities, resulting in a loss of minority carrier lifetime. In some cases the migration has proceeded further, so that the junctions have become excessively leaky, and all of the gain has been lost.

Contaminant films were seen on the dies and wires of some of the devices of both manufacturers, but the nature and source have not been determined. However, the material is not easily removed by water or alcohol, nor is it silicone material.



The rise of emitter forward voltage (V_{BE}), in some devices, as compared to the collector forward drop confirms the rise in silicon resistivity.

A plot showing cumulative failure distribution for Groups II and III was drawn for the National Semiconductor sample lot (Figures 4 and 5), but a complete plot for the Raytheon sample lot could not be drawn due to an absence of main failure points in the Group III testing (Figures 2 and 3). Figures 4 and 5 display the data for the National Semiconductor sample lot used to calculate an activation energy of 1.14eV.

A broken circle around a marked point, on the graph, indicates a freak failure not calculated as part of the regression line. A solid circle around a marked point indicates an isolated failure point. The regression line was drawn using the least square method.

The activation energy was calculated from the formula:

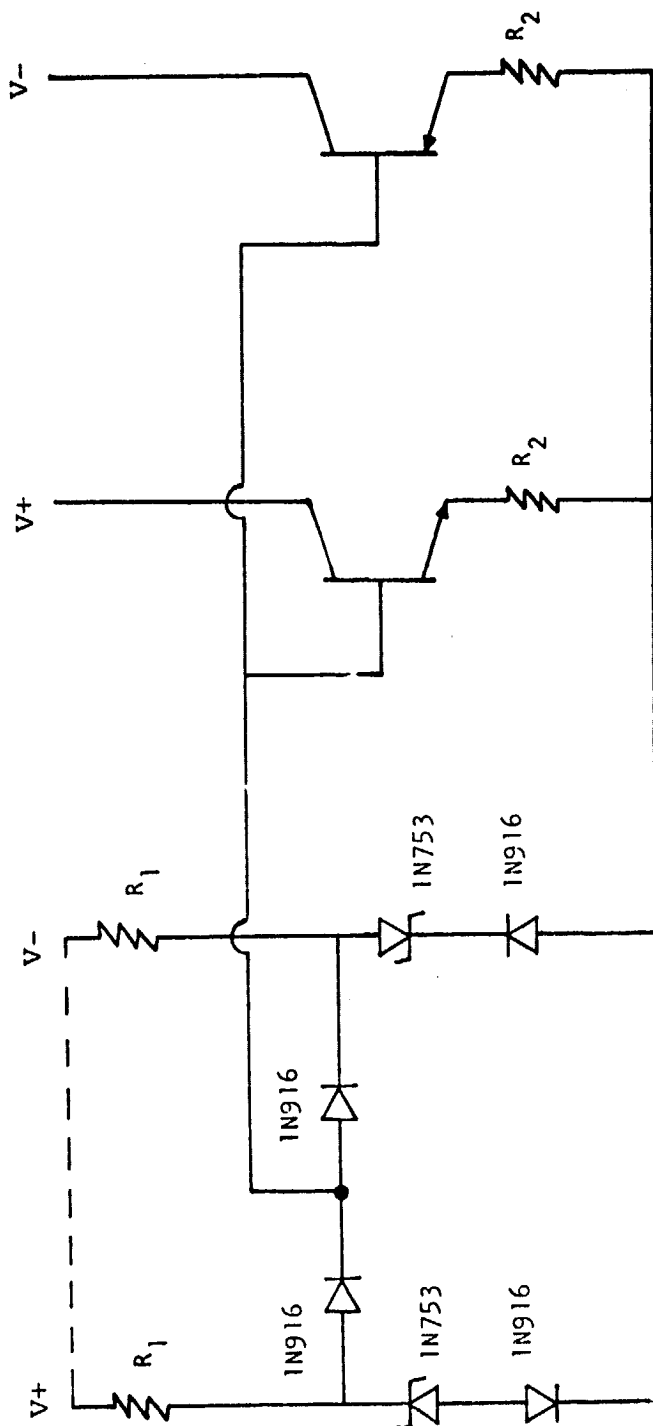
$$E = \left[\ln \left(\frac{t_1}{t_2} \right) \right] \left[\frac{8.63 \times 10^{-5} \text{ eV/}^\circ\text{K}}{\left(\frac{1}{T_1 + 273} \right) - \left(\frac{1}{T_2 + 273} \right)} \right] \text{ eV}$$

Where: t_1 = step of Group II - Temp Stress I = 160 hrs.

t_2 = step of Group III - Temp Stress II = 16 hrs.

T_1 = temperature in $^\circ\text{C}$ of 16% failure for Group II.

T_2 = temperature in $^\circ\text{C}$ of 16% failure for Group III.



NOTES: $R_1 = 800 \pm 5\%$, 2W. $R_2 = 107\Omega \pm 1\%$, $\frac{1}{2}$ W
Use V+ for NPN Transistors; Use V- for PNP Transistors.

FIGURE 1
Power/Temperature Stress Circuit
JANTX2N2369A



NOTE
FOR TABLES
4 THROUGH 7

The minimum/maximum initial and final data generally have an absolute accuracy of $\pm 1\%$ of the reading and $\pm$ one digit except for readings greater than 9.99mA which have an absolute accuracy of $\pm 2\%$ of the reading and $\pm$ one digit. The data also has a resolution for four digits. The standard deviations, means, delta means, and average means are, therefore, valid indicators of trends over time and temperature, excepting the minor statistical computer error of supplying a constant number of significant digits.



RAYTHEON

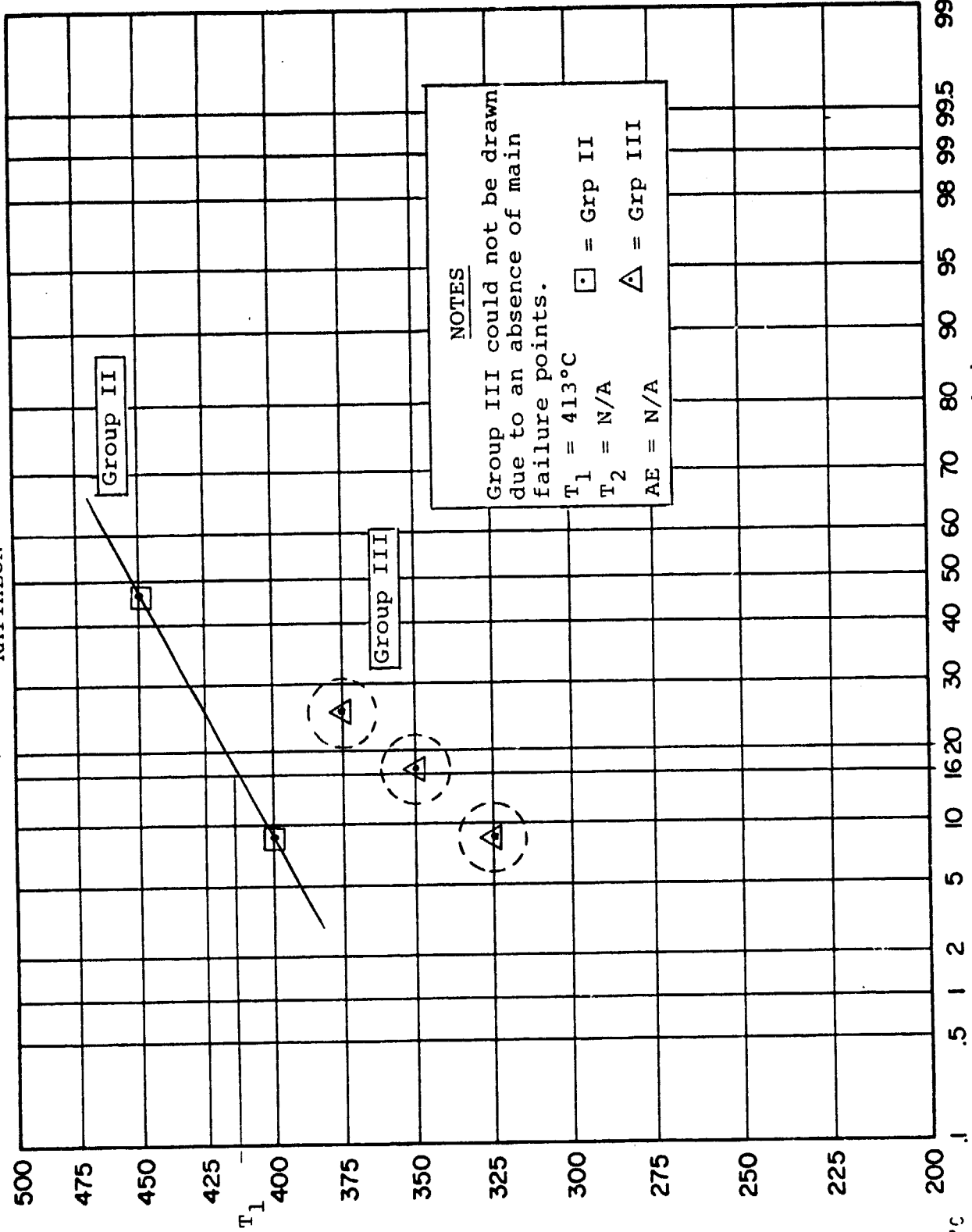
JANTX2N2369A

JANTX2N2369A

* JUNCTION TEMPERATURE (°C)

*NOTE

$$T_J \approx T_A + 175^\circ\text{C}$$



NOTES

Group III could not be drawn due to an absence of main failure points.

$T_1 = 413^\circ\text{C}$

$T_2 = \text{N/A}$

$\text{AE} = \text{N/A}$

□ = Grp II

△ = Grp III

FIGURE 2

Cumulative Percent Failures Versus Junction Temperature, Raytheon

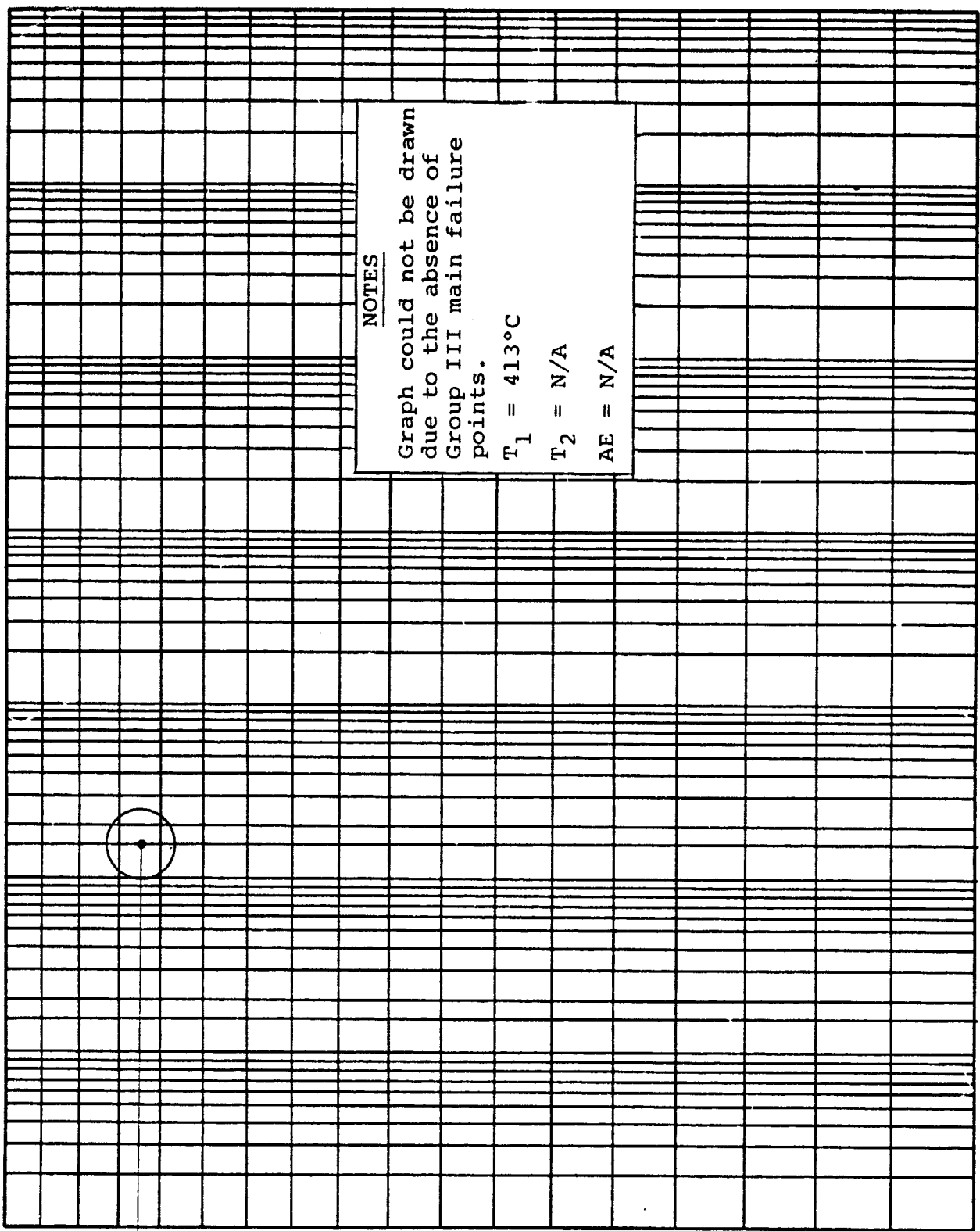


* JUNCTION TEMPERATURE (°C)

T_J

*NOTE

$T_J \approx T_A + 175^\circ\text{C}$



NOTES

Graph could not be drawn due to the absence of Group III main failure points.

T₁ = 413°C

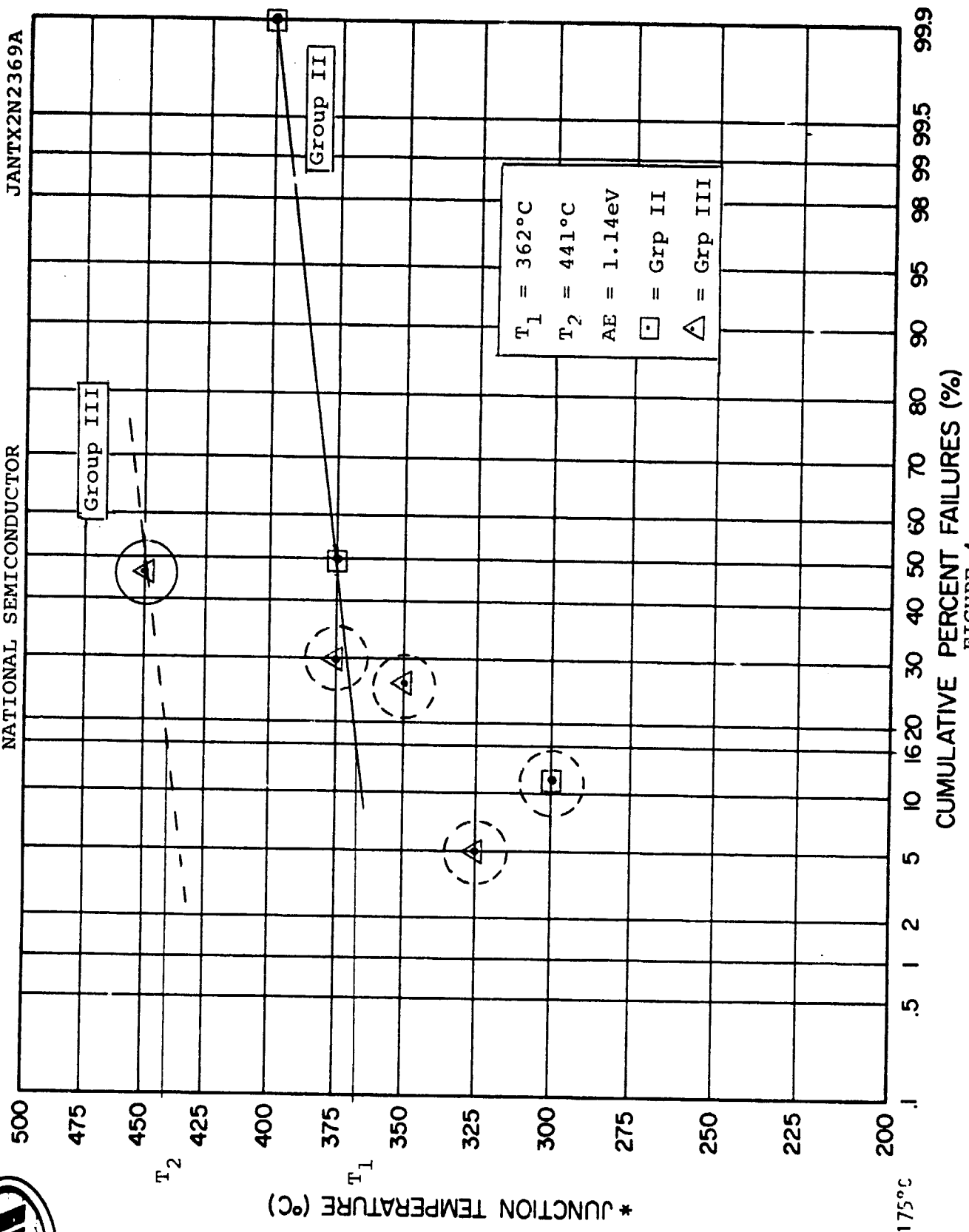
T₂ = N/A

AE = N/A

TIME (HOURS)

FIGURE 3

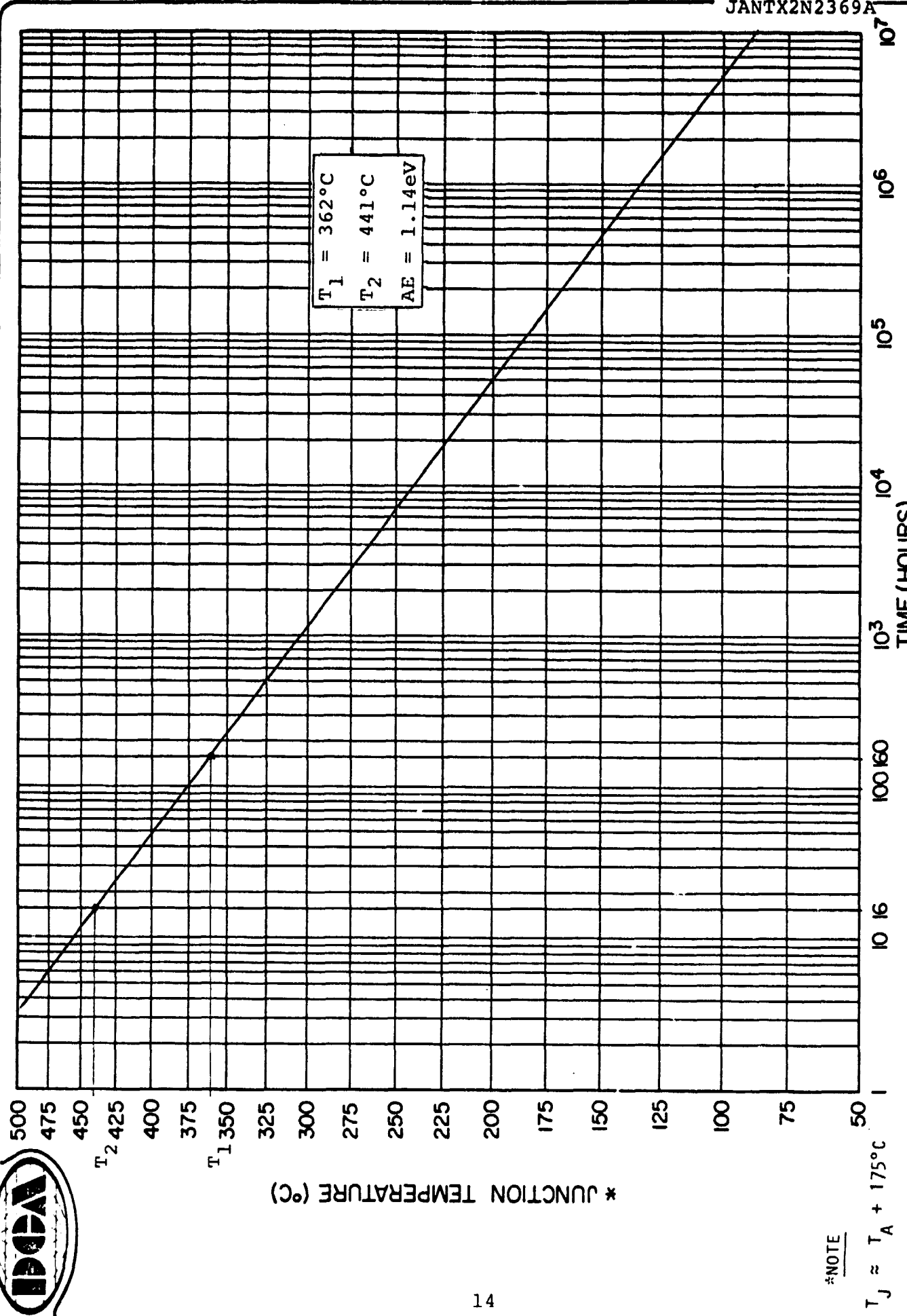
Time Steps Versus Junction Temperature, Raytheon



*NOTE

$T_J \approx T_A + 175^\circ\text{C}$

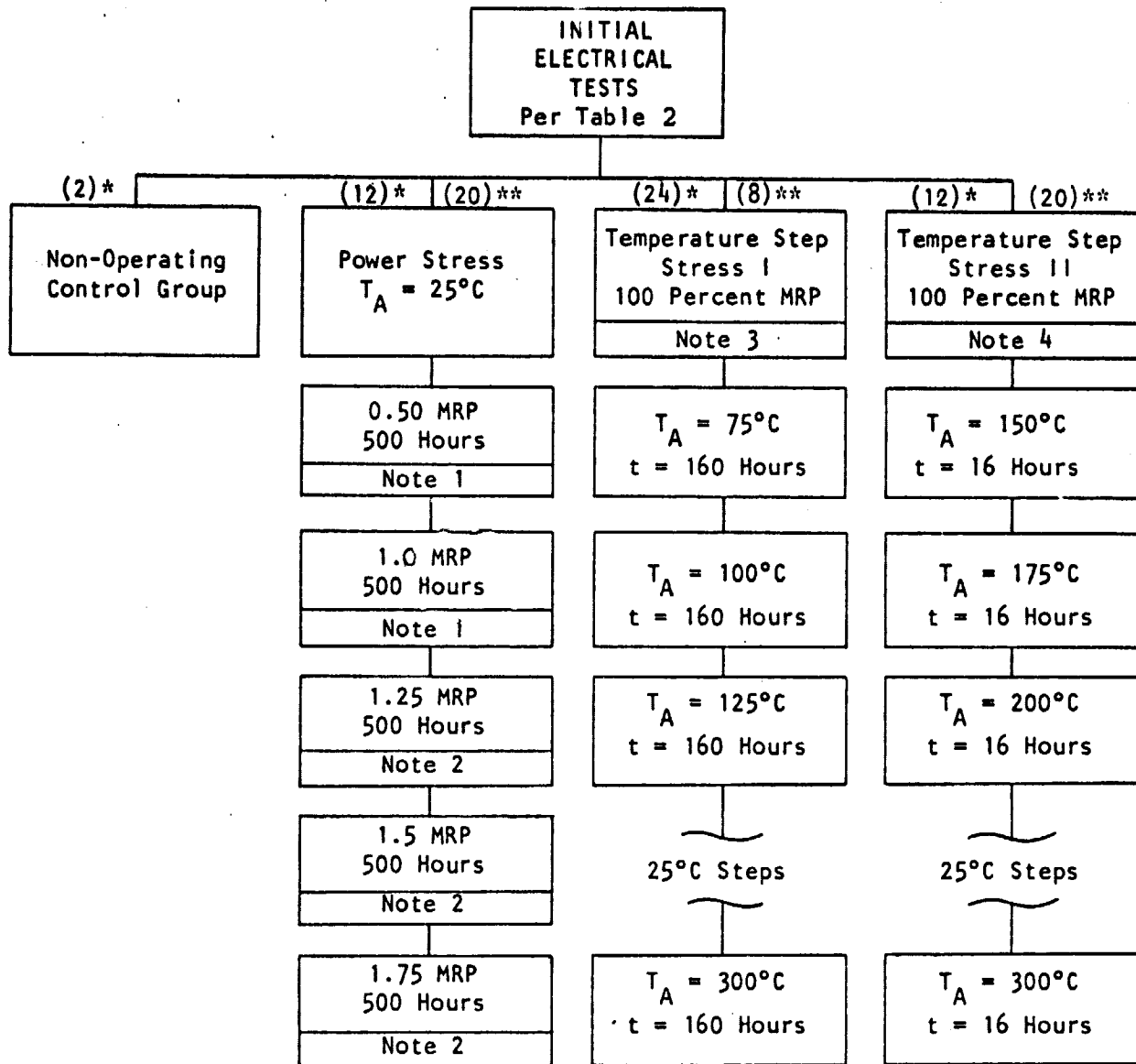
FIGURE 4
Cumulative Percent Failures Versus Junction Temperature, National Semiconductor



*NOTE

$T_J \approx T_A + 175^{\circ}\text{C}$

Time Steps Versus Junction Temperature, National Semiconductor
FIGURE 5

TABLE 1
TEST FLOW DIAGRAM

*Quantity per manufacturer (Raytheon)

**Quantity per manufacturer (National Semiconductor)

NOTES:

- 1) Electrical measurements per Table 2 were made at 50, 150, 250 and 500 hours.
- 2) Electrical measurements per Table 2 were made at 10, 25, 50, 150, 250 and 500 hours.
- 3) Electrical measurements per Table 2 were made at the end of each 160 hours.
- 4) Electrical measurements per Table 2 were made at the end of each 16 hours.



JANTX2N2369A

TABLE 2
PARAMETERS AND TEST CONDITIONS

PARAMETER	CONDITIONS	SPEC. LIMIT		CAT. LIMIT *		UNITS
		MIN	MAX	MIN	MAX	
I_{CES}	@ $V_{CE} = 20.0V$		.4		40	μA
$V_{CE(SAT)1}$	@ $I_C = 10mA$, $I_B = 1.0mA$		.2		.3	V
$V_{CE(SAT)2}$	@ $I_C = 100mA$, $I_B = 10mA$		.5		.75	V
h_{FE}	@ $V_{CE} = .35V$, $I_C = mA$ (PULSED)	40	120	20	180	-

NOTES: *

In addition, any open or short shall be considered catastrophic

TABLE 3
POWER STRESS BURN-IN CONDITIONS

$I_E = 52.8mA$	
$V_{CE} =$	Percent P_D
3.43V	50
6.90V	100
8.60V	125
10.30V	150
12.00V	175

TABLE 4
GROUP I - POWER STRESS DATA SUMMARY

Page 1 of 2

PARAMETER	$I_{CES} = .4\mu A (MAX)$		$V_{CE(SAT)1} = .20V (MAX)$		$V_{CE(SAT)2} = .50V (MAX)$		$h_{FE} = 40 (MIN) 120 (MAX)$	
CONDITIONS AND LIMIT	$@V_{CE} = 20.0V$		$@I_C = 10mA, I_B = 1.0mA$		$@I_C = 100mA, I_B = 10mA$		$@V_{CE} = .35V, I_C = 10mA (PULSED)$	
IDENTIFICATION	RAYTHEON	NATIONAL	RAYTHEON	NATIONAL	RAYTHEON	NATIONAL	RAYTHEON	NATIONAL
INITIAL DATA								
MIN VALUE	4.25nA	4.48nA	125.0mV	141.0mV	241.0mV	293.0mV	55.80	52.20
MAX VALUE	65.00nA	146.00nA	159.0mV	169.0mV	343.0mV	398.0mV	95.90	85.10
MEAN	35.80nA	45.27nA	145.7mV	155.1mV	294.1mV	327.9mV	80.21	64.77
STD DEV	20.46nA	47.37nA	10.33mV	7.641mV	31.61mV	27.67mV	11.50	9.798
INTERIM DATA								
POWER 50 TO 125% Δ MEAN VALUE								
50% POWER								
50 HOURS	-32.95nA	-41.74nA	-1.9mV	-1.6mV	-1.8mV	-1.8mV	-1.38	.52
150 HOURS	-32.48nA	-41.31nA	-1.6mV	-1.7mV	-.5mV	-1.1mV	-.02	1.46
250 HOURS	-32.64nA	-41.60nA	-1.8mV	-1.9mV	-.8mV	-1.9mV	-.44	.95
500 HOURS	-32.85nA	-41.94nA	-2.1mV	-2.4mV	-1.8mV	-2.9mV	-.34	1.18
100% POWER								
550 HOURS	-32.73nA	-41.25nA	-2.0mV	-1.6mV	-1.5mV	-1.8mV	.56	2.21
650 HOURS	-32.71nA	-42.32nA	-2.4mV	-2.7mV	-1.0mV	-3.8mV	.14	1.47
750 HOURS	-33.36nA	499.47 μA^*	-2.9mV	35.2mV*	-3.3mV	-1.6mV	.05	-.86
1000 HOURS	-33.55nA	-42.75nA	-3.4mV	-4.9mV	-3.8mV	-6.0mV	-.07	3.40
125% POWER								
1010 HOURS	13.89nA	1.05mA*	-1.8mV	-1.5mV	-2.4mV	-.2mV	.58	2.68
1025 HOURS	-33.08nA	-41.48nA	-2.7mV	-2.3mV	-3.6mV	-2.2mV	.66	2.69
1050 HOURS	-33.39nA	-42.62nA	-3.3mV	-3.6mV	-3.9mV	-.8mV	.28	1.73
1150 HOURS	-32.52nA	-41.87nA	-1.7mV	-2.3mV	-2.6mV	-4.2mV	1.75	3.61
1250 HOURS	-32.98nA	-42.48nA	-1.6mV	-1.9mV	-2.3mV	-.1mV	1.17	2.90
1500 HOURS	-33.43nA	-42.66nA	-3.5mV	-3.9mV	-4.4mV	-4.2mV	.67	2.70

(continued on second sheet)

TABLE 4 (Cont'd)
— POWER STRESS DATA SUMMARY

Page 2 of 2

(continued from first sheet)

GROUP I

PARAMETER	$I_{CES} = .4\mu A (MAX)$	$V_{CE(SAT)} I_B = 1.0mA$	$V_{CE2} = .50V (MAX)$	$h_{fe} = 40 (MIN) 120 (MAX)$
CONDITIONS AND LIMITS	$@V_{CE} = 20.0V$	$@I_C = 10mA, I_B = 1.0mA$	$@I_{CE} = 100mA, I_B = 10mA$	$@V_{CE} = .35V, I_C = 10mA (PULSED)$
IDENTIFICATION	RAYTHEON	NATIONAL	RAYTHEON	NATIONAL
INITIAL DATA				
MIN VALUE	4.25nA	4.49nA	241.0mV	55.80
MAX VALUE	65.00nA	146.00nA	343.0mV	95.90
MEAN	35.90nA	45.27nA	294.1mV	80.21
STD DEV	20.46nA	47.37nA	31.61mV	11.50
INTERIM DATA				
POWER 150 TO 175% Δ MEAN VALUE				
150% POWER				
1510 HOURS	-33.42nA	-42.73nA	-4.0mV	1.12
1525 HOURS	-33.57nA	-42.98nA	-2.8mV	.67
1550 HOURS	-33.19nA	-42.44nA	-3.8mV	1.53
1650 HOURS	-33.70nA	-43.03nA	-4.7mV	.89
1750 HOURS	-32.75nA	-42.72nA	-2.3mV	2.81
2000 HOURS	-33.34nA	-42.90nA	-3.1mV	1.37
175% POWER				
2010 HOURS	-33.50nA	-40.42nA	803.9mV*	-4.63
2025 HOURS	-33.54nA	-43.04nA	-2.8mV	2.25
2050 HOURS	-33.53nA	-43.05nA	-3.0mV	2.50
2150 HOURS	-33.43nA	-42.85nA	-2.6mV	2.74
2250 HOURS	-32.44nA	-42.03nA	3.2mV	4.35
2500 HOURS	-32.61nA	-42.17nA	.3mV	3.99
FINAL DATA				
MIN VALUE	1.20nA	1.84nA	243.0mV	57.90
MAX VALUE	5.77nA	4.10nA	341.0mV	101.00
MEAN	3.19nA	3.10nA	294.4mV	84.20
STD DEV	1.65nA	.750nA	32.84mV	12.22

NOTE: * Catastrophic Rejects removed from data after this point.



TABLE 5

JANTX2N2369A

JANTX2N2369A

GROUP II TEMP STRESS DATA SUMMARY (160 HR INCREMENTS)

PARAMETERS		$I_{CES} = .4\mu A$ (MAX)		$V_{CE(SAT)1} = .20V$ (MAX)		$V_{CE(SAT)2} = .50V$ (MAX)		$h_{FE} = 40$ (MIN) 120 (MAX)	
CONDITIONS AND LIMITS		$@V_{CE} = 20.0V$		$@I_C = 10mA, I_B = 1.0mA$		$@I_C = 100mA, I_B = 10mA$		$@V_{CE} = .35V, I_C = 10mA$ (PULSED)	
IDENTIFICATION									
INITIAL DATA									
MIN VALUE		RAYTHEON		NATIONAL		RAYTHEON		NATIONAL	
MAX VALUE									
MEAN									
STD DEV									
INTERIM DATA (INITIAL TO FINAL)									
Δ MEAN VALUE									
TOTAL HRS									
160		- .079nA		-1.088nA		-2.1mV		-2.6mV	
320		- .061nA		- .510nA		- .9mV		-1.8mV	
480		-1.166nA		-8.641nA		-3.6mV		-3.0mV	
640		- .691nA		-8.686nA		-3.5mV		-1.3mV	
800		.190nA		-8.000nA		-2.4mV		2.9mV	
960		1.348nA		-7.606nA		1.1mV		41.0mV	
1120		2.344nA		-7.782nA		16.5mV		537.4mV*	
1280		1.338nA		-8.034nA		422.6mV*		537.1mV*	
1440		- .916nA		409.990 μ A*		581.6mV*		729.7mV*	
1600		JOB STOPPED		JOB STOPPED		JOB STOPPED		JOB STOPPED	
300°C									
75°C									
100°C									
125°C									
150°C									
175°C									
200°C									
225°C									
250°C									
275°C									
300°C									
75°C									
100°C									
125°C									
150°C									
175°C									
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75°C									
100°C									
125°C									
150°C									
175°C									
200°C									
225°C									
250°C									
275°C									
300									



TABLE 6

DATA SUMMARY (16 HR INCREMENTS)

GROUP III

TEMP STRESS

PARAMETERS		$I_{CES} = .4\mu A$ (MAX)		$V_{CE}(SAT)_1 = .20V$ (MAX)		$V_{CE}(SAT)_2 = .50V$ (MAX)		$h_{FE} = 4$ (MIN) 120 (MAX)	
CONDITIONS AND LIMITS		$@V_{CE} = 20.0V$		$@I_C = 10mA, I_B = 1.0mA$		$@I_C = 100mA, I_B = 10mA$		$@V_{CE} = .35V, I_C = 10mA$ (PULSED)	
IDENTIFICATION		RAYTHEON		NATIONAL		RAYTHEON		NATIONAL	
INITIAL DATA		RAYTHEON		NATIONAL		RAYTHEON		NATIONAL	
MIN VALUE		.880nA		1.410nA		233.0mV		52.50	
MAX VALUE		3.170nA		9.990mA		330.0mV		98.40	
MEAN		1.699nA		499.500μA		271.3mV		74.39	
STD DEV		.713nA		2.177mA		24.61mV		13.09	
EXPERIM DATA (INITIAL TO FINAL)									
Δ MEAN VALUE									
TOTAL HRS									
TEMP (T _A)									
16		832.49 μA		0.69 nA		401.9 mV		3.74	
32		*768.49 μA		*2.50 mA		-0.3 mV		11.07	
48		*999.09 μA		*303.40 μA		0.9 mV		11.41	
64		0.66 nA		0.36 nA		2.1 mV		6.36	
80		40.02 nA		33.33 nA		4.3 mV		1.68	
96		1.07 nA		0.73 nA		4.5 mV		-1.37	
112		1.22 nA		1.74 nA		12.5 mV		-15.15	

TABLE 7
FINAL DATA SUMMARY

PARAMETER	SPECIFICATIONS LIMIT		U N I T S	MEAN INT. DATA	AVERAGE Δ IN MEAN VALUE					
	MIN	MAX			POWER STRESS		TEMPERATURE STRESS I		TEMPERATURE STRESS II	
					RAYTHEON	NATIONAL	RAYTHEON	NATIONAL	RAYTHEON	NATIONAL
I _{CES}	--	.4	μA		-.03130	+59.556±	+.00026	+45.549±	+371.44±	
V _{CE(SAT)1}	--	.2	V		+.02891	+.04325	+.11214	+.40609	+.06091	
V _{CE(SAT)2}	--	.5	V		+.02864	+.04462	+.20438	+.83516	+.01477	
h _{FE}	40	120			+.90769	+1.4873	-7.1322±	-13.452±	+2.5343	

NOTE: Catastrophic reject(s) removed from data after final test point.



TABLE 8 STEP STRESS CATASTROPHIC FAILURE SUMMARY

JAN TX2N2369A

JANTX2N2369A

GROUP I POWER STRESS

TEST STEP	MFR A		MFR B	
	QTY.	NOTE	QTY.	NOTE
50% 50 hr.	0	-	0	-
100 hr.	0	-	0	-
100 hr.	0	-	0	-
250 hr.	0	-	0	-
100% 50 hr.	0	-	0	-
100 hr.	0	-	0	-
100 hr.	0	-	1	F
250 hr.	0	-	0	-
125% 10 hr.	0	-	1	E
15 hr.	0	-	0	-
25 hr.	0	-	0	-
100 hr.	0	-	0	-
100 hr.	0	-	0	-
250 hr.	0	-	0	-
150% 10 hr.	0	-	0	-
15 hr.	0	-	0	-
25 hr.	0	-	0	-
100 hr.	0	-	0	-
100 hr.	0	-	0	-
250 hr.	0	-	0	-
175% 10 hr.	1	D	2	G
15 hr.	0	-	0	-
25 hr.	0	-	0	-
100 hr.	0	-	0	-
100 hr.	0	-	0	-
250 hr.	0	-	0	-

GROUP II 160 HR. TEMP. STEPS

TEST STEP (TA)	MFR A		MFR B	
	QTY.	NOTE	QTY.	NOTE
75°C	0	-	0	-
100°C	0	-	0	-
125°C	0	-	1	B
150°C	0	-	0	-
175°C	0	-	0	-
200°C	0	-	2	A
225°C	1	A	2	H
250°C	0	-	0	-
275°C	2	B	0	-
300°C	JOB STOPPED	JOB STOPPED	JOB STOPPED	JOB STOPPED

NOTES:

- (A) $h_{FE} < 20$
(B) $V_{CE2} > .75V$
(C) $V_{CE1} > .30V$
(D) NOTES A, B, & C
(E) $I_{CES} < 40mA$
(F) NOTES A, C, & E
(G) NOTES B & C
(H) NOTES A & B

GROUP III 16 HR. TEMP. STEPS

TEST STEP (TA)	MFR A		MFR B	
	QTY.	NOTE	QTY.	NOTE
150°C	1	A	1	A
175°C	1	E	4	E
200°C	1	E	1	E
225°C	0	-	0	-
250°C	0	-	0	-
275°C	0	-	2	B
300°C	0	-	0	-

MFR "A" = RAYTHEON

MFR "B" = NATIONAL SEMICONDUCTOR



FAILURE SUMMARY

PARAMETRIC

STEP STRESS

TABLE 9

GROUP I POWER STRESS

TEST STEP	MFR A		MFR B	
	QTY.	NOTE	QTY.	NOTE
50% 50 hr.	0	-	0	-
100 hr.	0	-	0	-
100 hr.	0	-	0	-
250 hr.	0	-	0	-
100% 50 hr.	0	-	0	-
100 hr.	0	-	0	-
100 hr.	0	-	0	-
250 hr.	0	-	0	-
125% 10 hr.	0	-	1	D
15 hr.	0	-	0	-
25 hr.	0	-	0	-
100 hr.	0	-	0	-
100 hr.	0	-	0	-
250 hr.	0	-	0	-
175% 10 hr.	0	-	0	-
15 hr.	0	-	0	-
25 hr.	0	-	0	-
100 hr.	0	-	0	-
100 hr.	0	-	0	-
250 hr.	0	-	1	A

GROUP II 160 HR. TEMP. STEPS

TEST STEP (T _A)	MFR A		MFR B	
	QTY.	NOTE	QTY.	NOTE
75°C	1	E	0	-
100°C	0	-	0	-
125°C	0	-	0	-
150°C	0	-	0	-
175°C	0	-	0	-
200°C	1	C	1	F
225°C	2	1	1	B
250°C	0	-	0	-
275°C	4	2	0	-
300°C	JOB STOPPED		0	-

GROUP III 16 HR. TEMP. STEPS

TEST STEP (T _A)	MFR A		MFR B	
	QTY.	NOTE	QTY.	NOTE
150°C	0	-	0	-
175°C	0	-	0	-
200°C	0	-	0	-
225°C	0	-	2	B
250°C	0	-	1	B
275°C	0	-	1	2
300°C	2	B	7	1

MFR "A" = RAYTHEON

MFR "B" = NATIONAL SEMICONDUCTOR

NOTES:

(A) V_{CE1} MAXIMUM LIMIT FAILURE(B) h_{FE} MINIMUM LIMIT FAILURE(C) V_{CE2} MAXIMUM LIMIT FAILURE(D) S/N 2099 PULLED FROM LOT AS MIL-S-19500 h_{FE} LIMIT FAILURE(E) h_{FE} MAXIMUM LIMIT FAILURE

(F) NOTES B & C

(G) NOTES A & C



JANTX2N2369A

FAILURE ANALYSIS



MSFC STEP-STRESS TEST
FAILURE ANALYSIS
TRANSISTORS

JANTX2N2369A

Date 13 October 1978

J/N 2CN242-02B P/N 2N2369A MFR National Semiconductor

FAILURE VERIFICATION: LIMIT: 0.4μA MAX. LIMITS: 40 to 120

S/N	BV _{CEO} -volts-	BV _{CBO} -volts-	I _{CES} -μA- @V _{CE} = 20V	BV _{EBO} -volts-	h _{FE} @I _C = 10mA V _{CE} = 0.35 V	V _{BEO} -volts- @I _{BEO} = 10mA	Initial Rej. @ Test Seq. Number:	Initial Reject For:	V _{CE} (SAT) @I _C = 10mA I _B = 1.0mA
2135	33 (S) @5 MA	38 (S) @5 MA	1.2MA	3.3 (S) @5 MA	NONE	1.4*	13 (200°C)	h _{FE} , V _{CE}	NONE
			*V _{BCO}	= 0.88	VOLTS				
2137	48	54	3.1nA	5.7	17	0.90	13 (200°C)	h _{FE} , V _{CE}	0.21
2139	55	55	2.5nA	5.6	24	0.93	15 (225°C)	h _{FE} , V _{CE}	0.22

INTERNAL VISUAL INSPECTION:

All three National Semiconductor Company samples exhibit severe gold-aluminum intermetallic ("purple plague") formation over 100% of the aluminum metallization. In addition, S/N 2135 and 2137 show some metal migration between the base and emitter fingers; S/N 2139 has transparent material condensed on the wires and die. (See Figure A-1.)

*h_{FE} trace present. Cannot meet stated test conditions. (Leaky)
**h_{FE} trace very leaky.

D = drift H = hysteresis Inv = inversion R = resistive S = soft Uns = unstable



MSFC STEP-STRESS TEST
FAILURE ANALYSIS
TRANSISTORS

JANTX2N2369A

Date 13 October 1978

J/N 2CN242-02B P/N 2N2369A MFR RAYTHEON

FAILURE VERIFICATION: LIMIT:
0.4 MAX.

LIMITS:
40 to 120

S/N	BV _{CEO} -volts-	BV _{CBO} -volts-	I _{CES} -μA- @V _{CE} = 20V	BV _{EBO} -volts-	h _{FE} @I _C = 10mA V _{CE} = 0.35V	V _{BEO} -volts- @I _{BEO} = 10mA	Initial Rej. @ Test Seq. Number:	Initial Reject For:	V _{CE} (SAT) @I _C = 10mA I _B = 1.0mA
2182	47	48	1.8nA	5.2	23	0.81	18 (275°C)	h _{FE} , V _{CE}	0.18
2188	41	52(D)	3.1nA	5.4	22	0.88	15 (225°C)	h _{FE}	0.18
2191	42	60	16 nA	5.4	33	0.89	15 (225°C)	h _{FE} , V _{CE}	0.16

INTERNAL VISUAL INSPECTION:

All three Raytheon samples exhibit gold-aluminum intermetallics on the base and emitter metallization. (See Figure A-2.)

S/N 2191 also has electromigration voids in the aluminum metallization which barely maintain electrical continuity to the base contact. (See Figure A-3.)

S/N's 2182 and 2188 have a slight condensation of unidentified foreign material on the wires.

*h_{FE} trace present. Cannot meet stated test conditions. (Leaky)
**h_{FE} trace very leaky.

D = drift H = hysteresis Inv = inversion R = resistive S = soft Uns = unstable



CONCLUSIONS

Both the National and the Raytheon parts suffered a loss of h_{FE} while generally continuing to maintain good junction quality with low leakage. This situation indicates loss of emitter efficiency as the cause of the decline in h_{FE} . The loss of emitter efficiency is in turn due to migration of gold and possible other impurities within the bulk silicon, resulting in a loss of minority carrier lifetime. In the case of S/N 2135, the migration has proceeded further so that the junctions have become excessively leaky, and all h_{FE} has been lost.*

The nature and source of the contaminant films on the die and wires of S/N 2137, and wires of S/N 2139, 2182, and 2188 have not been determined. However, it is not easily removed in water or alcohol, nor is it a silicone material. The most likely source would be from co-plated organics deposited during the electroplating of the package parts, which were later sublimed by the heat of the stress testing.

*The rise of V_{BEO} (emitter forward voltage) of S/N 2135, as compared to the collector forward drop, confirms the rise in silicon resistivity caused by the increased gold doping of this device. The gold has not yet reached the collector side of the die, but is getterred by the phosphorous of the emitter at this point in the cycle of destruction.



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JANTX2N2369A



FIGURE A-1

S/N 2137, Typical National Semiconductor Die Geometry, 193X

Note "purple plague" formation and condensed spots
of contaminant.

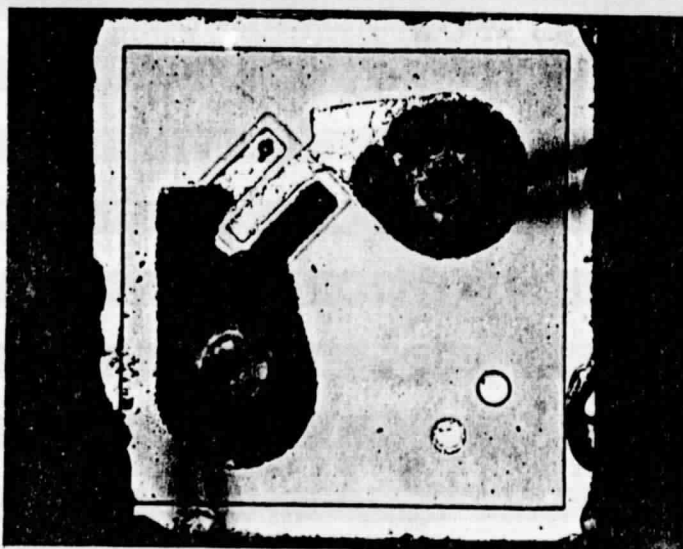


FIGURE A-2

S/N 2182, Typical Raytheon Die Geometry, 176X

Note "purple plague" formation.



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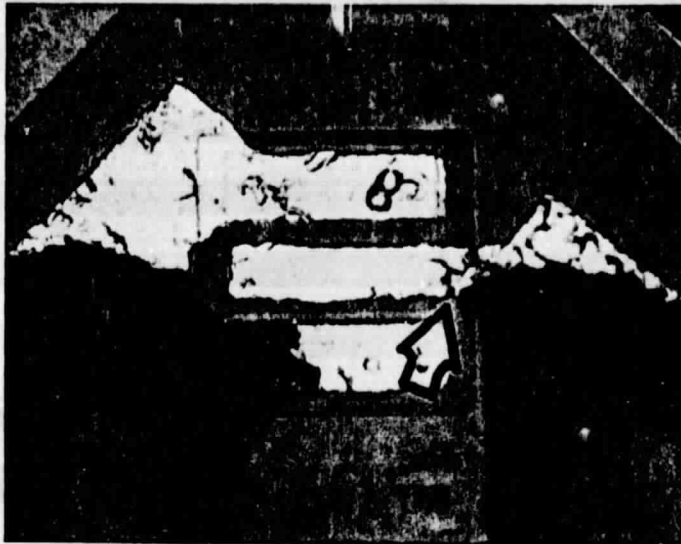


FIGURE A-3

S/N 2191, Raytheon, 400X

Arrow indicates void in aluminum metallization
of the base finger.

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